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(54) **ELECTROSURGICAL GENERATOR**

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(51) **Int. Cl.**

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A61B 18/12	(2006.01)
A61B 18/14	(2006.01)
A61B 18/00	(2006.01)

(52) **U.S. Cl.**

CPC ***A61B 18/1206*** (2013.01); *A61B 18/1445* (2013.01); *A61B 2018/0063* (2013.01); *A61B 2018/0072* (2013.01); *A61B 2018/00577* (2013.01); *A61B 2018/00601* (2013.01); *A61B 2018/00648* (2013.01); *A61B 2018/00702* (2013.01); *A61B 2018/00827* (2013.01); *A61B 2018/00875* (2013.01); *A61B 2018/00892* (2013.01)

(58) **Field of Classification Search**

CPC A61N 1/00; A61B 18/00; A61B 18/02; A61B 18/04; A61B 18/06; A61B 18/08; A61B 18/10; A61B 18/12; A61B 18/14; A61B 18/16; A61B 18/18; A61B 5/05; A61B 5/053

USPC 606/34; 607/7, 11, 30

See application file for complete search history.

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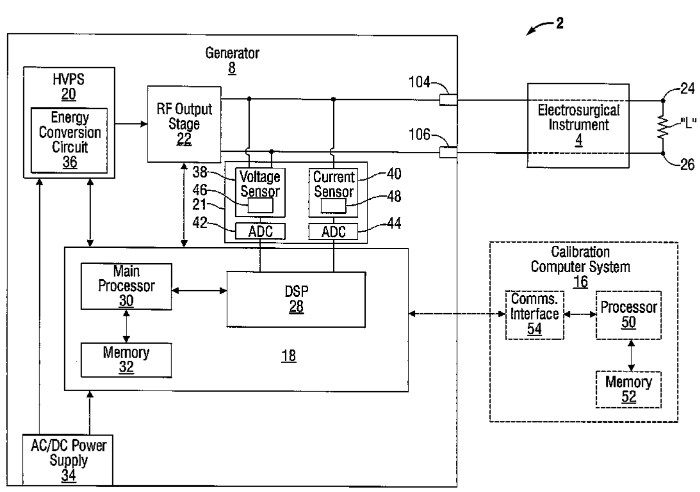
(57) **ABSTRACT**

An electrosurgical system for performing an electrosurgical procedure is provided and includes an electrosurgical generator and a calibration computer system. The electrosurgical generator includes one or more processors and a measurement module including one or more log amps that are in operative communication with the processor. The calibration computer system configured to couple to a measurement device and is configured to measure parameters of an output signal generated by the electrosurgical generator. The calibration computer system is configured to compile the measured parameters into one or more data look-up tables and couple to the electrosurgical generator for transferring the data look-up table(s) to memory of the electrosurgical generator. The microprocessor is configured to receive an output from the log amp(s) and access the data look-up table(s) from memory to execute one or more control algorithms for controlling an output of the electrosurgical generator.

12 Claims, 5 Drawing Sheets



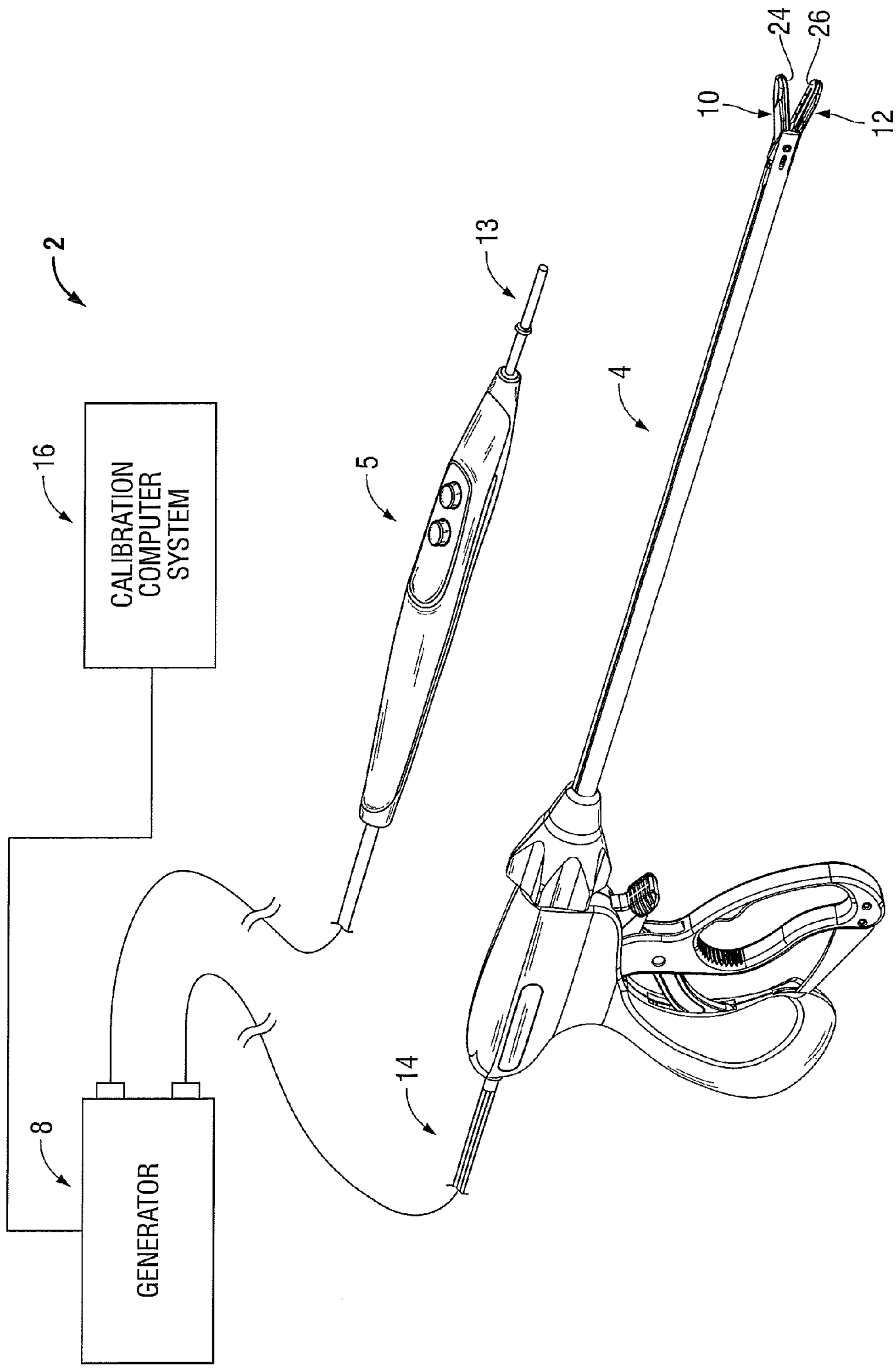

2
CALIBRATION
COMPUTER
SYSTEM
16
GENERATOR
8
5
13
4
10
12
24
26
14

Fig. 1

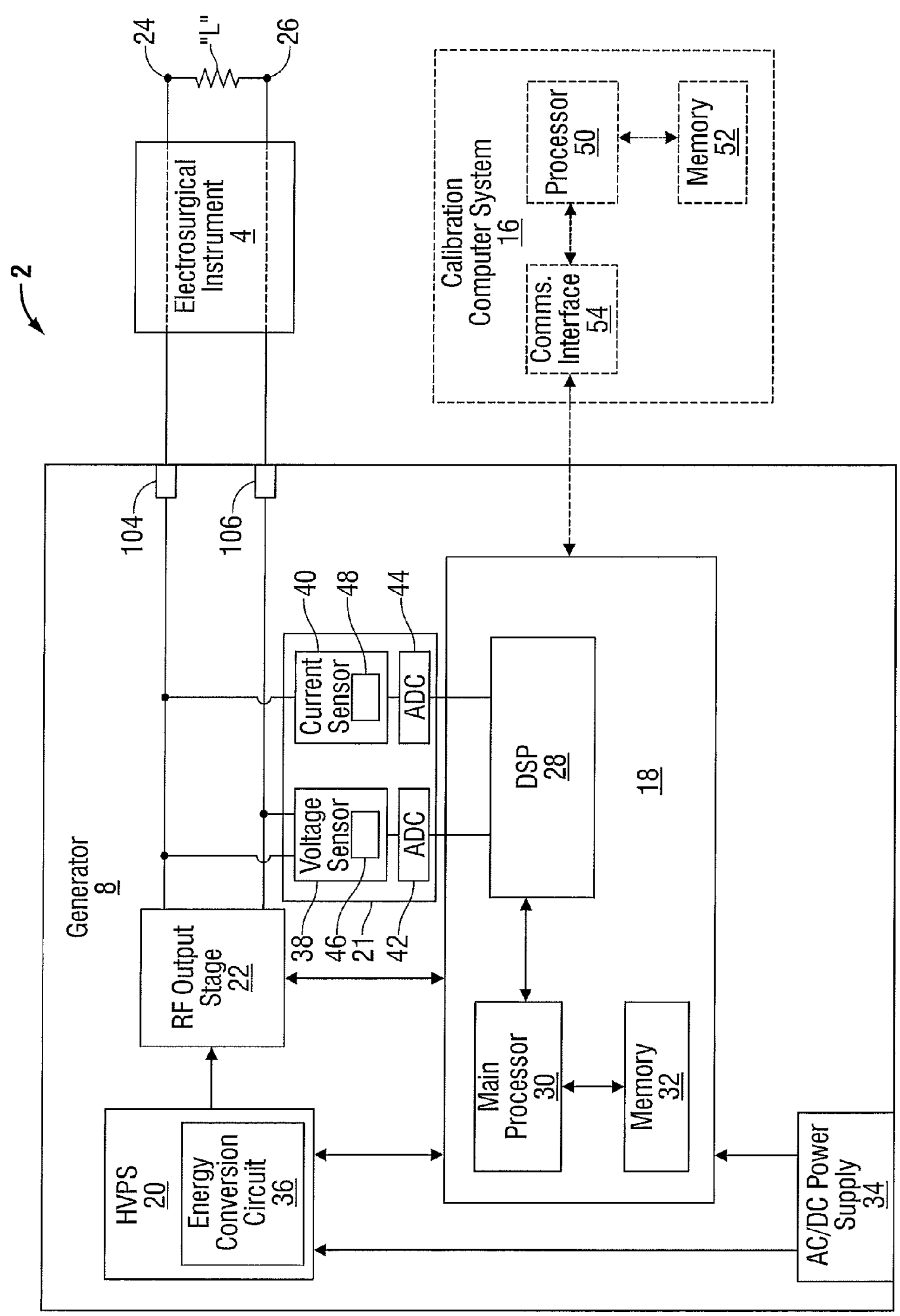

2
24
"L"
26
Electrosurgical Instrument 4
Calibration Computer System 16
Processor 50
Memory 52
Comms. Interface 54
104
106
Generator 8
RF Output Stage 22
40
48
44
Current Sensor
ADC
Voltage Sensor
ADC
38
46
21
42
DSP 28
18
Main Processor 30
Memory 32
HVPS 20
Energy Conversion Circuit 36
AC/DC Power Supply 34

Fig. 2

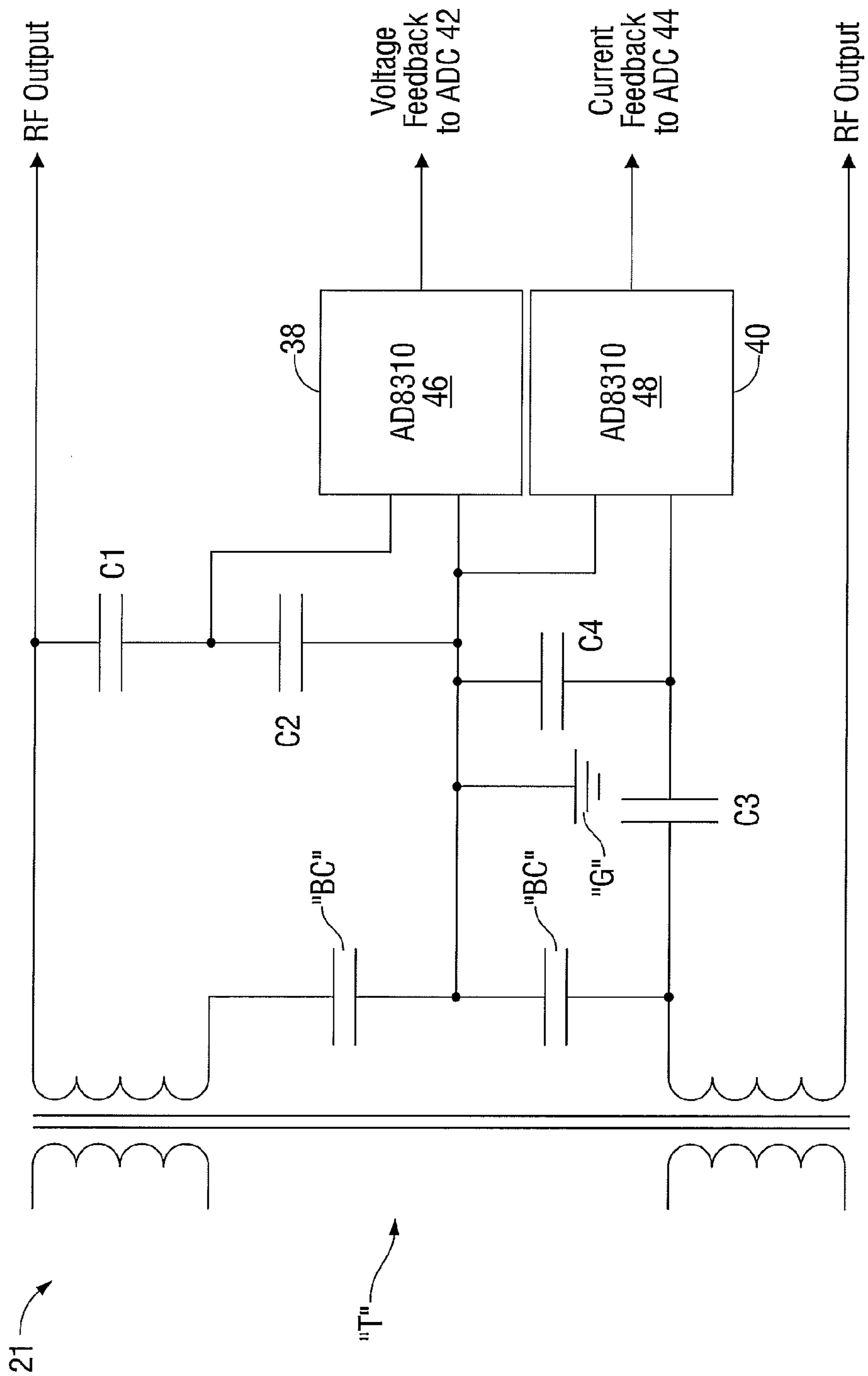

RF Output
Voltage Feedback to ADC 42
Current Feedback to ADC 44
RF Output
38
AD8310
46
AD8310
48
40
C1
C2
C4
C3
"BC"
"BC"
"G"
"T"
21

Fig. 3

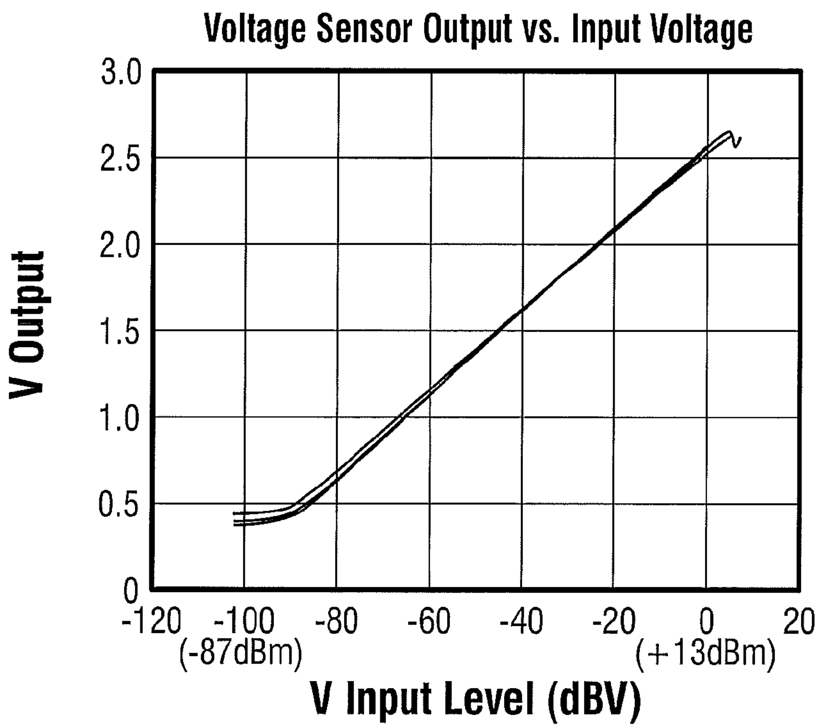

Voltage Sensor Output vs. Input Voltage
V Output
3.0
2.5
2.0
1.5
1.0
0.5
0
-120
-100
(-87dBm)
-80
-60
-40
-20
0
(+13dBm)
20
V Input Level (dBV)

Fig. 4

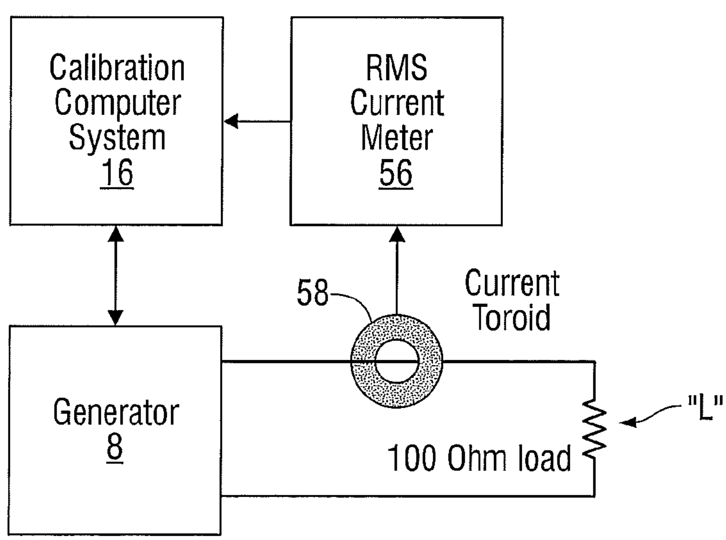

Calibration Computer System 16
RMS Current Meter 56
58
Current Toroid
Generator 8
"L"
100 Ohm load

Fig. 5

Impedance	Actual Irms	V1Raw	I1Raw	Calculated Vrms	Log V1	V1 Gain
100	0	0.3735	0.4622	0		
100	0.03	1.6479	0.9229	3	0.021	139.88
100	0.073	1.9614	1.3008	7.3	0.054	134.96
100	0.171	2.2368	1.5974	17.1	0.122	140.27
100	0.27	2.4031	1.7644	27	0.199	135.59
100	0.37	2.5188	1.8728	37	0.280	132.06
100	0.47	2.5994	1.9534	47	0.355	132.25
100	0.568	2.658	2.0171	56.8	0.422	134.45
100	0.698	2.718	2.083	69.8	0.504	138.41
100	0.796	2.7612	2.1255	79.6	0.573	138.95
100	0.893	2.7979	2.1687	89.3	0.638	139.88

Fig. 6

ELECTROSURGICAL GENERATOR

BACKGROUND

1. Technical Field

The present disclosure relates to an electrosurgical generator. More particularly, the present disclosure relates to electrosurgical generators having a gain calibrated RF logarithmic amplifier sensor.

2. Description of Related Art

RF generators configured for use with electrosurgical instruments are known in the art. In certain instances, one or more logarithmic amplifier, sometimes referred to as "log amps," may be incorporated into the circuitry of the RF generators to compress a large dynamic input range to a more manageable output for a digital signal processor of the RF generator. For example, a typical log amp can have an input range that varies by 10,000 times, e.g., from about 100 μV to about 1V. Conversely, a log amp output, typically, varies by 3 times, e.g., from about 1V to about 3V. To accomplish these log amp input and output ratios, log amps typically have a very high gain bandwidth, which is fairly constant. Due to internal construction of the log amps, however, the log amps have non-linear gain dependency at their inputs, which, in turn, results in decreased accuracy of log amp sensors associated with the log amps.

SUMMARY

In view of the foregoing, there exists a need for RF generators having one or more gain calibrated log amp sensors configured to compensate for gain variance at the input of the log amp.

Aspects of the present disclosure are described in detail with reference to the drawing wherein like reference numerals identify similar or identical elements. As used herein, the term "distal" refers to the portion that is being described which is further from a user, while the term "proximal" refers to the portion that is being described which is closer to a user.

An aspect of the present disclosure provides an electrosurgical system for performing an electrosurgical procedure. The electrosurgical system including an electrosurgical generator that includes at least one processor and a measurement module including at least one log amp in operative communication with the processor. A calibration computer system is configured to couple to a measurement device and is configured to measure parameters of an output signal generated by the electrosurgical generator. The calibration computer system is configured to compile the measured parameters into at least one data look-up table, and couple to the electrosurgical generator for transferring the at least one data look-up table to memory of the electrosurgical generator. The microprocessor is configured to receive an output from the at least one log amp and access the at least one data look-up table from memory to execute at least one control algorithm for controlling an output of the electrosurgical generator.

The at least one log amp may be configured to receive an output from a sensor that is configured to sense an output of the electrosurgical generator.

The measurement device may be a device that measures RMS current. In this instance, the measurement device may include a current toroid that is configured to measure an output current of the electrosurgical device.

The output from the at least one log amp may be a voltage output.

The parameters contained in the data look-up table may include gain of the at least one log amp, output voltage of the

at least one log amp, input voltage of the at least one log amp, output current of the electrosurgical generator and output voltage of the electrosurgical generator.

The at least one control algorithm may be configured to calculate a slope and gain of the log amp. The slope and gain of the log amp may be calculated through a dynamic operating range of the log amp. The log amp may be configured to allow a user to vary a slope thereof to obtain an optimum slope through the dynamic operating range.

The control algorithm may utilize a piece-wise linear fit of the gain relative to the measured output of the log amp to correct gain variations of the log amp. Moreover, the control algorithm may utilize an averaging technique of the gain relative to the measured output of the log amp to correct gain variations of the log amp. Further, the control algorithm may utilize a polynomial curve fitting technique of the gain relative to the measured output of the voltage log amp to correct the variations in gain.

The measurement module may include a voltage and current sensor that are configured to measure respective voltage and current on a patient side of an output transformer of the measurement module. The voltage and current sensors may be isolated from a patient and referenced to ground of the electrosurgical generator by isolating and/or reducing a voltage sense line with the use of one or more capacitors.

An aspect of the instant disclosure provides a computer calibration system for calibrating measurement circuitry of an electrosurgical device. The computer calibration system includes a measurement device that is configured to measure an output of the electrosurgical device. A memory that stores measurement data includes a plurality of current and voltage values of at least one log amp of the measurement circuitry, a plurality of gain values of the log amp, a plurality of current and voltage values of the electrosurgical device and a plurality of impedance values of a load coupled to the electrosurgical device. A processor may be configured to execute one or more control algorithms to compile the measurement data into at least one data look-up table. A communication interface may be configured for transferring the at least one data look-up table to memory of the electrosurgical device when the computer calibration system is coupled to the electrosurgical generator.

The at least one log amp may be configured to receive an output from a sensor that is configured to sense an output of the electrosurgical device.

The measurement device may be configured to measure RMS current. In this instance, the measurement device may include a current toroid that is configured to measure an output current of the electrosurgical device.

An aspect of the instant disclosure provides a method for calibrating measurement circuitry of an electrosurgical device. An output of the electrosurgical device is measured. An output of at least one log amp of the measurement circuitry of the electrosurgical device is measured. A data look-up table including measurement data obtained from the measuring steps is compiled. A slope and gain of the at least one log amp is calculated based on the measurement data obtained from the measuring step. At least one control algorithm utilizing the calculated slope and gain is executed. A gain of the log amp based on an output of the log amp to calibrate the measurement circuitry is recalculated.

The at least one control algorithm may utilize a piece-wise linear fit of the gain relative to the measured output of the log amp to correct gain variations of the log amp. Moreover, the at least one control algorithm may utilize either an averaging technique or a polynomial curve fitting technique of the log amp gain relative to the measured output of the voltage log amp to correct the variations in gain.

BRIEF DESCRIPTION OF THE DRAWINGS

Various embodiments of the present disclosure are described hereinbelow with references to the drawings, wherein:

FIG. **1** is a perspective view of an electrosurgical system including a generator, calibration computer system, and electrosurgical instrument(s) according to an embodiment of the present disclosure;

FIG. **2** is a block diagram of the electrosurgical system depicted in FIG. **1**;

FIG. **3** is a schematic diagram of an RF output stage of the generator depicted in FIGS. **1** and **2**;

FIG. **4** is graphical illustration of an output voltage of a log amp plotted against an input voltage of the log amp across the dynamic range of the log amp;

FIG. **5** is a block diagram of the electrosurgical system depicted in FIG. **1** coupled to a measuring device and a test load; and

FIG. **6** is a table illustrating tabulated measured and calculated data taken across a dynamic range of a log amp depicted in FIG. **2**.

DETAILED DESCRIPTION

Detailed embodiments of the present disclosure are disclosed herein; however, the disclosed embodiments are merely examples of the disclosure, which may be embodied in various forms. Therefore, specific structural and functional details disclosed herein are not to be interpreted as limiting, but merely as a basis for the claims and as a representative basis for teaching one skilled in the art to variously employ the present disclosure in virtually any appropriately detailed structure.

FIG. **1** is a perspective view of an electrosurgical system **2** that includes a calibration system **16** according to embodiments of the present disclosure. System **2** includes an electrosurgical generator **8** including electronic circuitry that generates radio frequency power for various electrosurgical procedures (e.g., sealing, cutting, coagulating, or ablating). The electrosurgical generator **8** may include a plurality of connectors to accommodate various types of electrosurgical instruments, e.g., a forceps **4**, pencil **5**, etc., that are configured to deliver the electrosurgical energy to tissue during a surgical procedure. In the illustrated embodiment, each of the forceps **4** and pencil **5** includes one or more electrodes that are configured to provide electrosurgical energy to treat tissue. For example, forceps **4** may be configured as a bipolar electrosurgical forceps including jaw members **10** and **12** (FIG. **1**) having a respective electrode **24**, **26** (FIGS. **1** and **2**) that are each connectable to the electrosurgical generator **8** via a cable **14** (FIG. **1**). Alternately, the forceps **4** may be a monopolar electrosurgical forceps, in which case one of the jaw members **10** and **12** includes an active electrode, and a return electrode is operably supported on a return pad (not shown) that is configured to contact a patient. In the illustrated embodiment, pencil **5** includes an active electrode **13**, and a return electrode is operably supported on a return pad (not shown) that is configured to contact a patient. For the remainder of the discussion, electrosurgical system **2** and calibration system **16** are described in terms of use with a bipolar electrosurgical forceps **4**.

FIG. **2** is a block diagram of an electrosurgical system **2**, which includes the generator **8**, forceps **4** and calibration computer system **16** of FIG. **1**. Briefly, generator **8** includes a controller **18**, a high voltage power supply **20**, and a radio frequency output stage **22**, which operate together to generate an electrosurgical signal to be applied to tissue through electrodes **24**, **26** of forceps **4**. Controller **18** includes a digital signal processor (DSP) **28**, a main processor **30**, and a memory **32**. The controller **18** may be any suitable microcontroller, microprocessor, PLD, PLA, or other digital logic device. Memory **32** may be volatile, non-volatile, solid state, magnetic, or other suitable storage memory.

The controller **18** may also include various circuitry that serves as an interface between the main processor **30** and other circuitry within the electrosurgical generator **8** (e.g., amplifiers and buffers). The controller **18** receives various feedback signals that are used by the main processor **30** and/or the DSP **28** to generate control signals to control various subsystems of the generator **8**, including the HVPS **20** and the RF output stage **22**. These subsystems are controlled to generate electrosurgical energy having desired characteristics for performing surgical procedures on tissue, which is represented in FIG. **2** by a test load "L."

The generator **8** includes an AC/DC power supply **34** that receives power from an alternating current (AC) line source (not explicitly shown) and converts the AC line power into direct current (DC), and, in turn, provides the DC power to an energy conversion circuit **36**. The energy conversion circuit **36** then converts the DC power at a first energy level into DC power at a second, different energy level based upon control signals received from the controller **18**. The energy conversion circuit **36** supplies the DC power at the second, different energy level to the RF output stage **22**. The RF output stage **22** converts the DC power into a high-frequency alternating current (e.g., RF), which may then be applied to tissue.

In accordance with the instant disclosure, the electrosurgical generator **8** includes a measurement module **21** (FIGS. **2** and **3**) that is configured to determine voltage, current, impedance, and power at a tissue site so that the controller **18** can use these measurements to control the characteristics of the electrosurgical output. The measurement module **21** includes a voltage sensor **38** and a current sensor **40** coupled to the output of the RF output stage **22** (FIG. **2**). The voltage sensor **38** senses the voltage across the output of the RF output stage **22** and provides, via a log amp **46**, an analog signal representing the sensed voltage to an analog-to-digital converter (ADC) **42**, which converts the analog signal representing voltage into digital form (FIGS. **2** and **3**). Similarly, the current sensor **40** senses the current at the output of the RF output stage **22** and provides, via a log amp **48**, an analog signal representing the sensed current to another ADC **44**, which converts the analog signal representing current into digital form (FIGS. **2** and **3**).

The DSP **28** receives the sensed voltage and sensed current data from the respective log amps **46** and **48** and uses it to calculate the impedance and/or the power at the tissue site. The main processor **30** of the controller **18** executes algorithms that use the sensed voltage, the sensed current, the impedance, and/or the power to control the HVPS **20** and/or the RF Output Stage **22**. For example, the main processor **30** may execute a PID control algorithm based upon the calculated power and a desired power level, which may be selected by a user, to determine the amount of electrical current that should be supplied by the RF output stage **22** to achieve and maintain the desired power level at the tissue site. As discussed in greater detail below, the DSP **28** utilizes one or more control algorithms to calibrate the received sensed voltage and current data to obtain a more accurate representation of the RMS voltage (Vrms) that is transmitted to the forceps **4**.

FIG. **3** illustrates a block diagram of internal components of the measurement module **21** including the voltage and current sensors **38** and **40** connected to the RF output stage **22**. Voltage and current sensors **38** and **40** are measured on the patient side of an output transformer "T." In the illustrated embodiment, both the voltage and current sensors **38** and **40** are duplicated for redundant sensing (only one of each is shown). The sensors **38**, **40** are isolated from the patient and are referenced to ground "G" of the generator **8** (FIG. **3**). With respect to the voltage, this is accomplished by isolating and reducing a voltage sense line with the use of a pair of capacitors C**1** and C**2** (FIG. **3**). For the current, a center tap transformer configuration is utilized including a pair of blocking capacitors "BC" between the ground "G" of the generator **8** and transformer "T". The blocking capacitors "BC" are used as a current sensing element instead of a traditional lossy element such as, for example, a resistor. The isolation and signal reduction for the current sense line is maintained using a pair of capacitors C**3** and C**4** (FIG. **3**). The capacitors C**1**-C**4** may be any suitable type of capacitors including without limitations polyphenylene sulphide (PPS) film capacitors, ceramic chip capacitors NPO (COG) and the like. In accordance with the instant disclosure, capacitors C**1**-C**4** are ceramic chip capacitors NPO (COG) and are chosen for their voltage and thermal stability. The aforementioned capacitor configuration facilitates maintaining a consistent overall gain of the measurement module **21** and, in particular log amps **46** and **48**.

Log amps **46** and **48** may be any suitable type of log amp. A suitable log amp may be an AD8310 manufactured by Analog Devices (FIG. **3**). This particular log amp was chosen because of its low current draw (e.g., approximately 8 mA), small footprint (e.g., approximately 4×5 mm), a suitable differential AC input that ranges from about −91 dBV to about 9 dBV, a suitable DC level output that ranges from about 0.4V to about 2.6V, and a large dynamic range that ranges from about −91 dB to about 4 dB. The AD8310 log amp utilizes minimal external components as compared to other log amps that are sometimes utilized in conventional generators. Other suitable log amps that may be utilized in accordance with the present disclosure include: AD8307, AD8318, AD8317, ADL5513, AD8363 (RMS) all manufactured by Analog Devices, HMC612LP manufactured by Hittite, LTC5507 manufactured by Linear Technology, and TL441 manufactured by Texas Instruments.

FIG. **4** shows a typical performance characteristic of an output of the log amp **46**. In accordance with the instant disclosure, a slope is used to derive a linear slope equation in the form of y=mx+b, where m is the slope of the output of the log amp **46** and b is the intercept of the log amp **46** at a 0 dBV input. The X axis shows the input in dBV and the Y axis shows the corresponding output of the log amp **46**. Log amp **46** includes a slope input (not explicitly shown) that gives the flexibility to increase the slope of the thereof. In accordance with the instant disclosure, to balance between input versus output range, the slope was increased to 40 mV/dB; this was done by adding a 23.2 KΩ resistor between two or more pins of the log amp **46**. With the increased slope of 40 mv/dB the output of the log amp **46** is 1.2V and an intercept point of the log amp **46** is 2.95 at the 0 dBV point, see FIG. **4**. The equation for the output of the log amp **46** is expressed as:

$$V\text{out}=0.040x+2.95 \tag{1}$$

where x is the value in dB of the input signal.

Equation (1) can be solved for x in volts (not dB) by rewriting equation (1) with dB:

$$V\text{out}=\text{Slope}*[20*\log(V\text{in})]+2.95 \tag{2}$$

the slope from equation (1) equals 0.04, Vin equals the input voltage to the log amp **46** and the 20 in equation (2) comes from the conversion of dBV to V which is:

$$dBV=20*\log(V) \tag{3}$$

solving for Vin:

$$V\text{in}=10\hat{}[(V\text{Out}-2.95)/(20*\text{Slope})] \tag{4}$$

the power of 10 comes from the inverse of the log function.

With reference again to FIG. **3**, the voltage signal into log amp **46** is a voltage divider using the ratio of C**1** and C**2**. This voltage signal is equal to:

$$V\_RF=V\_\text{Out}\times(XC_2/(XC_2+XC_1) \tag{5}$$

where XC=1/(2πfC), V_Out is the output voltage of the generator **8**, f is the operating frequency of the generator **8**, and C is the value of the capacitors.

The current signal into the log amp **40** may be derived from measuring the voltage integrated across the blocking capacitors "BC". The voltage across the blocking capacitor "BC" is related to the current through the blocking capacitor "BC" using the equation:

$$dv=I\times dt/C \tag{6}$$

where I is the output current of the generator **8**, C is the value of the blocking capacitor "BC", dv is the change in voltage across the capacitor "BC", and dt is the switching cycle time.

In some embodiments, to reduce noise on the current signal, a differential pair (not explicitly shown) may be run from the blocking capacitors "BC" back to an input of the log amp **48**. In particular, a low pass differential filter (with a pole of suitable frequency, e.g., about 100 KHz) may be added in series with the log amp **48**. One or more low pass differential filters may also be added in series with the log amp **46** to facilitate reducing noise on the current signal.

The aforementioned configuration of the log amps **46** and **48** and low pass filter facilitates maintaining a consistent overall gain of the measurement module **21**.

To accurately control the electrosurgical energy applied to tissue, the controller **18** needs to accurately sense the voltage and current at the tissue. As noted above, however, the voltage sensed by the voltage sensor **38** and the current sensed by the current sensor **40** may be inaccurate because of the internal construction of the log amps **46** and **48**. In particular, log amps **46** and **48** may have an internal gain that is dependent on the input voltage such that the gain of the log amps **46** and **48** is not constant across a dynamic range of the log amps **46** and **48**. The dynamic range of the log amps **46** and **48** may be measured from a voltage minimum (or current minimum) to a voltage maximum (or current maximum). This gain variation present for both log amps **46** and **48** may result in decreased accuracy of log amp sensors **38** and **40**. In other words, the voltage and current measured at the RF output stage **22** by the voltage and current sensors **38**, **40** may not equal the actual voltage and current at the load "L" (e.g., tissue) because of the non-linear gain dependency at the inputs of the log amps **46** and **48**.

The electrosurgical system **2** is configured to calibrate sensors **38** and **40** to compensate for the gain losses of the log amps **46** and **48** that introduce errors into the sensor data provided by the sensors **38** and **40**. In particular, a slope of the log amps **42** and **44** and an overall gain of the measurement module **21** is calculated via the calibration computer system **16**. In accordance herewith, the overall gain of the measurement module **21** takes into account the voltages from the capacitor divider network, attenuation due to the filter, and the gain through the log amp **38** and/or **40**. For illustrative purposes, the overall gain of the measurement module **21** is obtained using the gain of the log amp **46** that relates to measurements sensed by the voltage sensor **38**.

The slope and gain are calculated via calibration computer system **16**. Calibration computer system **16** is in connection with the controller **18** of the generator **8** and includes a processor **50**, a memory **52**, and a communications interface **54**. Calibration computer system **16** utilizes one or more suitable measuring devices to measure output voltage and current. In the illustrated embodiment, a RMS meter **56** in communication with a current toroid **58** is utilized to measure output current Irms sent to the test load "L" as shown in FIG. **5**. The output voltage Vrms can be obtained by multiplying the output current by the resistance of the test load "L."

In some embodiments, the generator **8** is connected to the calibration computer system **16**, RMS meter **56** including the current toroid **58**, and a 100 ohm test load "L." In this instance, for example, calibration computer system **16** configures the generator **8** to operate in an open loop mode, sets a target value(s), and turns on the generator **8** until the generator reaches the target value(s). In some embodiments, the power supply duty cycle of the generator **8** is varied to produce an RF output from 4 volts rms to 92 volts rms, e.g., through the dynamic range of the log amps **46** and **48**. Calibration computer system **16** records the data measured by the generator **8** and RMS current meter **56**, see table (1) in FIG. **6**. In embodiments, this data can be loaded into one or more suitable templates, e.g., a formatted Excel template, for analysis of a load curve to plot error.

Table (1) in FIG. **6** lists the impedance of the test load "L", e.g., a 100Ω load, measured Irms, V**1**raw (output voltage of log amp **46**), I**1**raw (output current of log amp **48**) and calculated Vrms which is obtained by multiplying a corresponding Irms by the test load "L" impedance (e.g., 0.893 A×100Ω=89.3 V). The processor **50** accesses measurement data of table (1) and stores the measurement data in the memory **32** of the generator **8**. This data is accessible by the DSP **28** to execute one or more control algorithms for controlling an output of the generator **8**.

In some instances, the slope is calculated by dividing the dynamic range of the output of the voltage log amp **46** over the measured range of the output of the generator **8** in dB using the following equation:

$$\text{Slope}=(\text{Log}_{out}\_\text{max}-\text{Log}_{out}\_\text{min})/((20\times\log(\text{Gen}_{out}\_\text{max}))-(20\times\log(\text{Gen}_{out}\_\text{min}))) \tag{7}$$

where $\text{Log}_{out}\_\text{max}$ is the maximum output value of the log amp **38** recorded (2.7979), $\text{Log}_{out}\_\text{min}$ is the minimum value of the log amp **38** recorded (1.6479, (0.3735 in this column is used to verify the offset of the log amp **46** at no output of the generator **8**; this offset should be between 0.3 to 0.5)), $\text{Gen}_{out}\_\text{max}$ is the max output of the generator **8** (89.3) and $\text{Gen}_{out}\_\text{min}$ is the min output of the generator **8** (3, (the 0 may be ignored)). It has been found that the slope of the log amp **46** is equal to about 39 mV/dB and is linear over the dynamic range, as shown in FIG. **4**, for example.

To measure the gain of the log amp **46** (e.g., overall gain of the measurement module **21**), first the output voltage of the log amp **46** is translated to an input voltage, using the following equation:

$$V\text{in}=10\hat{}[(V\text{out}-2.95)/(20^*\text{Slope})] \tag{8}$$

where the "slope" is the slope of the voltage log amp **46** and Vout is the Vraw from table (1). The output of the log amp **46** equals 2.7979V at a calculated output voltage Vans from the generator **8** of 89.3V. Placing this into equation (4) and using the 39 mV for the slope, the input voltage is 0.638V, see Log V**1** column of table (1) in FIG. **6**; this is the actual voltage at the input of the log amp **46**. The gain can now be calculated using the equation:

$$\text{Gain}V=\text{Calculated}\_V\text{rms}/V\text{in} \tag{9}$$

in this instance the gain is equal to 139.88 (e.g., 89.3 v/0.638 v). The gain for each measured output voltage Vraw of the log amp **46** and corresponding output voltage Vrms of the generator **8** can be calculated in a similar manner and recorded. As can be appreciated, the more measurements taken through the dynamic range of the log amp **46** the more accurate the calculate gain will be. Multiplying equation (4) with the gain calculated in equation (9) gives an accurate representation of the output of the generator **8** referenced to the output of the log amp **46** when the generator **8** is coupled to a test load, see equation (10) below.

$$\text{Out}=\text{Gain}^*10\hat{}[(V\text{out}-2.95)/(20^*\text{Slope})] \tag{10}$$

Equation (10) is stored in memory **32** and, in some instances, may be utilized in a control algorithm by the DSP to calculate the output of the generator **8** in a real time scenario.

As can be appreciated, the Vrms is, however, not measured with an external device, e.g., an RMS meter **56**, in a real time scenario. As noted above, the gain of the log amp **46** (and/or log amp **48**) is not constant across the dynamic range, see FIG. **6** for example under the V**1** Gain column. The gain value changes from **132** to **140** in a non-linear relation. This gain variation is prevalent for both log amps **46** and **48**. Therefore, in a surgical environment, the DSP **28** utilizes one or more control algorithms to calculate the gain to calibrate the sensor **38** and/or sensor **40**. The DSP **28** uses the above data to fully automate the calibration of the sensor **38** (and/or sensor **40**) by calculating the slope of the log amp **46** (and/or log amp **48**) utilizing one or more of the aforementioned equations. The overall gain of the measurement module **21** is subsequently calculated and utilized by the DSP **28** to accurately calculate the Vrms, impedance and/or the power at the tissue site.

In particular, and in one embodiment, the calibration computer system **16** utilizes a control algorithm that incorporates a piece-wise linear fit of the gain relative to the measured output of the log amp **46** to correct the variations in gain of the log amp **46**. In this instance, for example, the data of table (1) may be stored into memory **22** and accessed by the DSP **28**. When the output of the voltage log amp **46** detected by the DSP **28** falls between two known values the gain is calculated using a linear slope equation:

$$\text{Gain\_Calc}=mX+b \tag{11}$$

in this equation Gain_Calc is the calculated gain value, X is the V**1**raw data from table (1), m is the slope between the two known gain points, and b is a calculated offset. It should be noted that the "Gain_Calc" in equation (11) is not the same as the "Gain" in equation (10). Gain_Calc" is the gain between two gain values (e.g., 134.96 and 140.27) previously calculated and stored into memory **22**. For example, if the detected output from the log amp **46** is 2.10, which falls between an output of log amp **46** that equals 1.96 (see table (1) in FIG. **5**) and an output of the log amp **46** that equals 2.24 (see table (1) in FIG. **5**) the DSP **28** utilizes equation (11) below and the corresponding gains to calculate the Gain_Calc.

$$m=(\text{Gain2}-\text{Gain1})/(\text{Log\_out2}-\text{Log\_out1}) \tag{11}$$

To calculate m, Gain **1** is a first gain point (134.96), which corresponds to an output of the log amp **46** that equals 1.96 and Gain **2** is a second gain point (140.27), which corresponds to an output of the log amp **46** that equals 2.24 (see FIG. **6**).

Log_out**1** is the output of the voltage log amp **46** in relation to the first gain point (1.96) and Log_out**2** is the output of the voltage log amp **46** in relation to the second gain point (2.24), see FIG. **6**. In this example, m is equal to 18.96.

$$b=\text{Gain1}-m^*(\text{Log\_out1}) \tag{12}$$

Continuing with the present example, and using equation (12) above, b is calculated to be equal to 97.8.

Taking the values found for b and m and using them in equation (11), the corresponding output of the log amp **46** is equal to 2.10 and the gain is found to be equal to 137.62.

The DSP **28** utilizes this gain value of 137.62 in equation (10) to accurately calculate Vrms, impedance and/or the power at the tissue site. The slope is assumed to equal 39 mV. The calculated value of the gain (137.62) is substituted into equation (10), Vrms is calculated to be (137.62)10^[(2.10−2.95)/(20×0.039)], which is equal to Vrms=(137.62)10^(−0.85/0.78), which is equal to Vrms=(137.62)10^(−1.089), which is equal to Vrms=11.192. This value of Vrms falls between the previously measured Vrms values 17.1 and 7.3 that correspond to the outputs 2.24 and 1.96 of the log amp **46**.

In some embodiments, the calibration computer system **16** utilizes a control algorithm that incorporates an averaging technique of the gain relative to the measured output of the log amp **46** to correct the variations in gain of the log amp **46**. In this instance, the log amp **46** gain values from the individual calibration points across the dynamic range are averaged together to get a mean gain for the error over the dynamic range of the voltage log amp **46**. In this instance, the DSP **28** calculates the mean gain value over the dynamic range and substitutes this gain in equation (10) and then calculates the Vrms (or other desired parameter at the tissue site).

In some embodiments, the calibration computer system **16** utilizes a control algorithm that incorporates a polynomial curve fitting technique ("poly-fit" technique) of the gain relative to the measured output of the log amp **46** to correct the variations in gain of the log amp **46**. In this instance, one or more suitable polynomials may be utilized to represent the gain variations of the voltage log amp **46**. For example, a typical third order polynomial:

$$V=a^*V\text{calc}^{\wedge 3}+b^*V\text{calc}^{\wedge 2}+c^*V\text{calc}+d$$

where a, b, c, and d are the polynomial calibration coefficients may be utilized to represent the gain variations of the voltage log amp **46**.

Operation of the electrosurgical system **2** is described with reference to the piece-wise linear fit algorithm. In this instance, it is assumed that the data of table (1) has been previously calculated for the log amp **46** and stored into memory **32** of the main processor **30**.

In use, the DSP **28** receives an output, e.g., an output voltage, from the log amp **46**. DSP **28** runs through the piece-wise linear fit control algorithm to calculate a gain of the log amp **46**. Thereafter, the Vrms is calculated utilizing the calculated gain in equation (10). Once the Vrms is calculated, the DSP **28** can communicate control signals as needed to ensure that the generator **8** provides a correct amount of electrosurgical energy to the forceps **4**.

The electrosurgical system **2** including the generator **8** and calibration computer system **16** provides an effective method of calibrating the sensors **38** and **40** to overcome the aforementioned drawbacks that are typically associated with conventional generators.

From the foregoing and with reference to the various figure drawings, those skilled in the art will appreciate that certain modifications can also be made to the present disclosure without departing from the scope of the same. For example, various temperature ranges could utilize their own multi-point calibrations to compensate for any temperature dependency of the log amp **46** and/or log amp **48**.

Moreover, it is within the purview of the instant disclosure to utilize a plurality of log amps **46** and a plurality of log amps **48**. As can be appreciated, this adds an extra layer of sensing capabilities, which, in turn may increase overall gain of the measurement module **21**.

Further, the aforementioned control algorithms may utilized in combination with one another. For example, the DSP **28** may utilize a piece-wise linear control algorithm across a first portion of the dynamic range of the log amps **46** and **48** and may utilize the averaging (or poly-fit) control algorithm across a second, different portion of the dynamic range of the log amps **46** and **48**.

While several embodiments of the disclosure have been shown in the drawings, it is not intended that the disclosure be limited thereto, as it is intended that the disclosure be as broad in scope as the art will allow and that the specification be read likewise. Therefore, the above description should not be construed as limiting, but merely as exemplifications of particular embodiments. Those skilled in the art will envision other modifications within the scope and spirit of the claims appended hereto.

What is claimed is:

1. An electrosurgical system for performing an electrosurgical procedure, comprising:

an electrosurgical generator including at least one microprocessor and a measurement module including at least one log amp in operative communication with the processor; and

a calibration computer system operably coupled to a measurement device configured to measure parameters of an output signal generated by the electrosurgical generator, the calibration computer system configured to compile the measured parameters into at least one data look-up table and couple to the electrosurgical generator for transferring the at least one data look-up table to memory of the electrosurgical generator,

wherein the microprocessor is configured to receive an output from the at least one log amp and access the at least one data look-up table from memory to execute at least one control algorithm for controlling an output of the electrosurgical generator, the at least one control algorithm including:

calculating a slope and gain of the log amp; and

correcting gain variations of the log amp based on a piece-wise linear fit of the gain relative to the measured output of the log amp.

2. The electrosurgical system according to claim **1**, wherein the at least one log amp is configured to receive an output from a sensor that is configured to sense an output of the electrosurgical generator.

3. The electrosurgical system according to claim **1**, wherein the measurement device is an RMS current device.

4. The electrosurgical system according to claim **1**, wherein the measurement device includes a current toroid that is configured to measure an output current of the electrosurgical device.

5. The electrosurgical system according to claim **1**, wherein the output from the at least one log amp is a voltage output.

6. The electrosurgical system according to claim **1**, wherein the parameters contained in the data look-up table include at least one of gain of the at least one log amp, output voltage of the at least one log amp, input voltage of the at least one log amp, output current of the electrosurgical generator and output voltage of the electrosurgical generator.

7. The electrosurgical system according to claim **1**, wherein the slope and gain of the log amp are calculated through a dynamic operating range of the log amp.

8. The electrosurgical system according to claim **7**, wherein the log amp is configured to allow a user to vary a slope thereof to obtain an optimum slope through the dynamic operating range.

9. The electrosurgical system according to claim **7**, wherein both the voltage and current sensors are isolated from a patient and referenced to ground of the electrosurgical generator by at least one of isolating and reducing a voltage sense line with the use of a plurality of capacitors.

10. The electrosurgical system according to claim **1**, wherein the control algorithm utilizes an averaging technique of the gain relative to the measured output of the log amp to correct gain variations of the log amp.

11. The electrosurgical system according to claim **1**, wherein the control algorithm utilizes a polynomial curve fitting technique of the gain relative to the measured output of the voltage log amp to correct the variations in gain.

12. The electrosurgical system according to claim **1**, wherein the measurement module includes a voltage and a current sensor that are configured to measure voltage and current, respectively, on a patient side of an output transformer of the measurement module.

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